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NEAR WAKE MEASUREMENTS IN THE PRESENCE OF AN INSTRUMENTATION BOOM

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Robert J. Cresci and Edward M. Schmidt

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The research has been conducted under Contract Nonr 839(38) for PROJECT DEFENDER, and was made possible by the support of the Advanced Research Projects Agency under Order No. 529 through the Office of Naval Research.

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Department

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NEAR WAKE MEASUREMENTS IN THE PRESENCE OF AN INSTRUMENTATION BOOM[+]

by

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SUMMARY

A series of experimental tests were run to determine the effect on the near wake flow field of inserting an instrumentation boom in the base region of a sharp cone. Test data were obtained for a free stream Mach number of 7.7, Reynolds numbers corresponding to either completely laminar or fully turbulent flow on the cone surface, and for a 10° half angle cone with a boom length of one and a half base diameters.

The data was compared to the clean base configuration and it was found that the adjacent flow field was disturbed considerably by the presence of the boom.

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TABLE OF CONTENTS

Section		Page
I	Introduction	1
II	Model Design and Test Configuration	2
III	Presentation of Results	4
IV	Concluding Remarks	7
V	References	8

LIST OF ILLUSTRATIONS

Figure			Page
1	Photographs of Test Model		9
2	Test Configuration		10
3	Static Pressure Distribution On Boom Surface		11
4	Heat Transfer Distribution To Boom Surface		12
5	Stagnation Temperature Profiles	(a) $\bar{x}=1.0$	13
5	Stagnation Temperature Profiles	(b) $\bar{x}=1.25$	14
5	Stagnation Temperature Profiles	(c) $\bar{x}=1.5$	15
6	Pitot Pressure Profiles	(a) $\bar{x}=1.00$	16
6	Pitot Pressure Profiles	(b) $\bar{x}=1.25$	17
6	Pitot Pressure Profiles	(c) $\bar{x}=1.50$	18
7	Static Pressure Profiles	(a) $\bar{x}=1.00$	19
7	Static Pressure Profiles	(b) $\bar{x}=1.25$	20
7	Static Pressure Profiles	(c) $\bar{x}=1.50$	21
8	Static Temperature Profiles	(a) $\bar{x}=1.00$	22
8	Static Temperature Profiles	(b) $\bar{x}=1.25$	23
8	Static Temperature Profiles	(c) $\bar{x}=1.50$	24

LIST OF SYMBOLS

d	cylindrical instrumentation arm diameter
D	base diameter
M	Mach number
p	pressure
p_t	pitot pressure
q	heat transfer rate
r	radial distance from centerline
Re	Reynolds number based on free stream conditions
T	temperature
x	Axial distance from model base
$(\bar{\ })$	Nondimensionalized with respect to base diameter

Subscripts

c	cone shoulder conditions
s	stagnation conditions
w	cone surface conditions
∞	free stream conditions
1	local flow conditions
2	local flow conditions behind a normal shock

SECTION I

INTRODUCTION

In order to obtain some near wake measurements on a conical body during a re-entry flight trajectory, it has been proposed to extend an instrumentation boom out of the base of the vehicle. This boom would support survey rakes and also contain instruments and optical equipment for obtaining direct measurements of the adjacent flow field. One of the difficulties associated with the interpretation of such data is the determination of whether the presence of the boom has altered the local flow conditions to be measured. This effect, if present, can invalidate the results of the entire flight test program. As a result, it is extremely important to establish the presence and extent of disturbance to the near wake flow field before the flight test program is initiated.

It is the purpose of the present report, therefore, to test the desired configuration (a sharp, 10° half angle cone) in a wind tunnel both for the "clean base" condition and with the instrumentation boom installed. Comparison of the two sets of data will indicate the extent of alteration of the flow field in the near wake. In addition, surface pressures and heat transfer rates on the boom will be measured for utilization in the structural design of the boom. The Mach 8 blowdown tunnel of the Polytechnic Institute of Brooklyn Aerospace Laboratory was chosen for the test series since the Reynolds number variation in this tunnel will produce a surface boundary layer on the model which is either completely laminar or fully turbulent at the shoulder (cf. reference 1). The desired flight trajectory includes both of these conditions.

Reference (2) presents the results of a similar study at a higher free stream Mach number; the free stream Reynolds number of these tests was similar to the laminar flow case for the present tests. Local density and temperature profiles were

measured therein using electron beam techniques while in the PIB tests, pitot pressures, static pressures, and total temperatures were obtained. From the present data, the local Mach number distribution can be obtained and comparison of local static conditions (e.g. density and temperature) between the two sets of data is thus possible.

In the following sections, the details of the model configuration, test conditions, and experimental results are described. Following this, suggestions for instrumentation locations are given based on the test results.

The authors are pleased to acknowledge the assistance of the staff of the Hypersonic Facility in obtaining the data and also of Professor M. H. Bloom for his discussions and suggestions concerning this program.

SECTION II

MODEL DESIGN AND TEST CONFIGURATION

Photographs of the test model are presented in figure (1) with the base boom installed; figure (2) shows a schematic of the model installation in the tunnel. The model consists of a 10° half angle cone with a sharp tip and a base diameter of eight inches. The boom is circular in cross section with a diameter of one tenth of the model base and a length of one and a half base diameters. The model is supported in the tunnel by wires which can be observed in figure (1). The effect of the support wires on the wake flow field has been shown to be negligible for the wire diameters and test conditions reported here, cf. references (2) through (5). Various configurations were tested; these include (i) the boom without instrumentation arms, (ii) the boom with wedge shaped (10° total included angle) arms and, (iii) the boom with cylindrical (d=1.5% D) arms. The instrumentation arms were extended to 3.5 inches from the centerline for both of the cross sectional configurations.

Probes were used to measure the flow field conditions in two difference planes; these correspond to the plane of the instrumentation arms (as seen in figure 1) and in a plane 45° from the arms. In the latter condition, the flow measurements were obtained by externally supported probes rather than by probes supported from the instrumentation arms. The data thus obtained indicates no difference between the two angular locations so that no distinction is made in the data plots.

The probes utilized in this investigation measure the static and pitot pressures and the stagnation temperatures of the flow. The static pressure probes are ogive tipped cylinders with six orifices drilled around the periphery of the cylinder roughly ten diameters downstream of the tip. These probes will not be too accurate where the flow inclination is large or where the local Mach number is large (due to viscous-inviscid interaction). For the present test conditions, however, these probes are found to be reasonably accurate since the flow inclination is quite small and the Mach numbers in the near wake are in the low supersonic regime. The pitot probes are of standard design while the stagnation temperature probes are open - tip, bare wire thermocouples stretched across two support struts. These probes can be seen in figure (1) on the right hand instrumentation arm. In addition to the flow field measurements, base pressures and boom surface pressures were obtained for various axial locations of the flow field probes. These data yield some information on the possible disturbance to the flow field caused by the probes; this is discussed in more detail in the following section.

Static pressures were measured by Hasting's type DV-13 thermocouple gauges while the pitot pressures were measured with both variable reluctance type and strain gauge transducers. All data were recorded on strip chart recorders.

The tests were run at an average stagnation temperature of 1900°R and a constant wall to stagnation temperature ratio (T_w/T_{s_∞}) of 0.29. The test Reynolds

numbers were 0.22 x 10^6 and 1.10 x 10^6 based on free stream conditions and the model base diameter. The actual test Mach number was 7.7 for the particular wind tunnel and Reynolds number range utilized in the present test series.

SECTION III

PRESENTATION OF RESULTS

The test data are presented in figures (3) through (8) for various model configurations, axial locations, and test Reynolds numbers. As shown in reference (1), the boundary layer at the cone shoulder is laminar for the lower Reynolds number and fully turbulent for the high Reynolds number tests. The data presented herein, therefore, will be referred to as "laminar" or "turbulent" corresponding to the condition of the surface boundary layer at the shoulder.

Figure (3) presents the static pressure distribution along the boom surface for various configurations. Several significant features can be observed from this data; first, it can be seen that there is no influence of the shape of the instrumentation arms or even the presence of the arms on the boom surface pressure for either the laminar or turbulent condition. The location of the probes used to obtain the profiles of temperature, pressure etc. was also varied while the boom surface pressure was being obtained. For the data for probe locations of $\bar{x} \leq 0.75$, the surface pressure distribution on the boom was slightly altered; thus, the profiles obtained at these locations were discarded since it wasn't clear whether the entire recirculation region was affected by the presence of the measuring probes.

The comparison between the boom surface pressure data and the centerline static pressure without the base boom is not as conclusive since the clean base data were obtained from reference (1) and were not available for values of $\bar{x}$ less than 1.0.

The few data points available for comparison, however, do seem to agree with the boom surface pressure data except at $\overline{x}=1.5$. At this location, the presence of the boom seems to decrease the local static pressure; this effect is more severe for the turbulent flow condition. The base pressure appears to be relatively unaffected by the presence of the boom.

Figure (4) presents the local heat transfer rate to the boom surface. For reference, the local values on the conical surface at the shoulder are also given. For the turbulent cone surface boundary layer, the heat transfer on the boom surface is considerably higher than for the laminar condition. In either case, however, the maximum heat transfer rate to the boom surface is less than that occuring on the cone surface at the particular test Reynolds number.

The measured stagnation temperatures, normalized with respect to the free stream value, are presented in figure (5) where radial profiles are plotted for different axial distances downstream of the model base. In all the following figures, the same symbols are utilized, the open ones indicating the clean base configuration, and the solid symbols indicating the data taken in the presence of the base boom. Again, there was no detectable difference in the profiles obtained with the boom alone or the boom with either the wedge or tubular instrumentation arms. Both the laminar and turbulent flow conditions are included in each figure. The major effects of the base boom appear to be in close proximity to the boom surface; the total temperature there approaches the boom surface temperature while in the tests without the boom, the local stagnation temperature is higher due to the free mixing along the flow centerline. For the turbulent flow condition there appears to be little discernible difference in the remaining portion of the profiles; for the laminar flow, however, the presence of the boom seems to decrease the overall temperature level somewhat.

Figure (6) presents the pitot pressure profiles obtained with the instrumenta-

tion boom alone and in the presence of the various probe arms; also included in these plots are the clean base data of reference (1) for comparison. The bands of data shown include the various boom configurations, but since there was no consistent observable trend for the different arms, no distinction is made in the presentation of the data. At $\overline{x} = 1.0$ there appears to be little difference in the data with and without the boom; for $\overline{x} = 1.25$, the laminar data shows an increase in local pitot pressure away from the boom surface due to the presence of the boom. At one and a half base diameters down stream, there is seen to be a considerable disturbance created by the boom out as far as the base radius of the cone for the laminar condition. A similar trend is observed for the turbulent case; however, the disturbance is not nearly as large. The corresponding static pressures, normalized with respect to free stream static pressure,are shown in figure (7) for the three axial locations. Here it is observed that within the experimental accuracy there is little effect of the boom and instrumentation arms for $\overline{x} = 1.0$ and 1.25. For the location 1.5 diameters downstream, the only influence of the boom appears to be in close proximity to the boom surface and the turbulent flow condition seems to be more severely affected. This effect is in contradistinction to both the total temperature data and the pitot pressure data obtained at this location.

From the pitot and static pressure data, the local Mach number distribution has been obtained and the resulting static temperature distribution then computed using the total temperature measurements. These profiles are presented in figure (8). A comparison with the clean base configuration data indicates a significant disturbance to the local static temperature field in the presence of the instrumentation boom. The disturbance is also seen to extend out practically to the cone radius and is present in both the laminar and turbulent flow conditions.

SECTION IV

CONCLUDING REMARKS

The experimental data involving flow field measurements in the near wake of a sharp 10° half angle cone with an instrumentation boom have been compared to previously obtained data without the boom and lead to several conclusions concerning the utilization of such a boom in free flight measurements. These are summarized briefly below.

(1) The static pressure field appears to be relatively unaffected by the presence of the boom except in close proximity to the boom surface.

(2) Pitot pressure profiles obtained with the boom are altered somewhat with respect to the clean base configuration. This effect is more significant in the laminar than in the turbulent data and becomes more severe as one progresses downstream. Since the static pressures are roughly the same, the Mach number distributions are altered significantly.

(3) Although there is an observable but small, change in the stagnation temperature profiles, the alteration of local Mach number caused by the boom has an even greater effect on the local static temperatures. Since this is one of the primary observables of interest in a free flight experiment, it appears that the present boom configuration would not be too useful in this respect; only outside of a region roughly 80% of the base radius does the flow (in terms of pressure, temperature, velocity, etc.) appear to be unaffected by the boom and instrumentation arms.

The particular design of the instrumenation arms appears to have no influence on the flow field, however, the boom configuration was found to have a considerable effect. This effect may change with Mach number so additional tests at higher Mach numbers are desirable. In addition, an asymmetric boom location may alleviate some of the disturbance since it would not impinge on the rear stagnation point in the recirculating flow.

SECTION V

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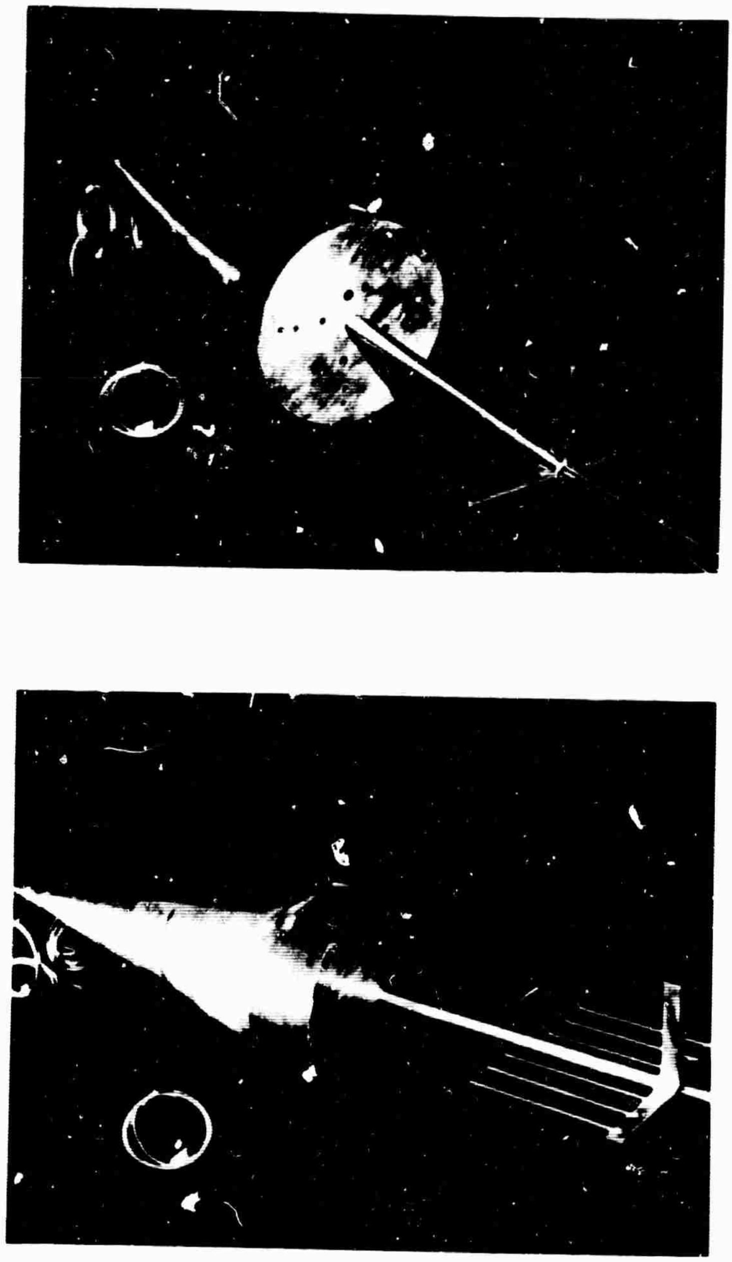

FIG. (I) PHOTOGRAPHS OF TEST MODEL

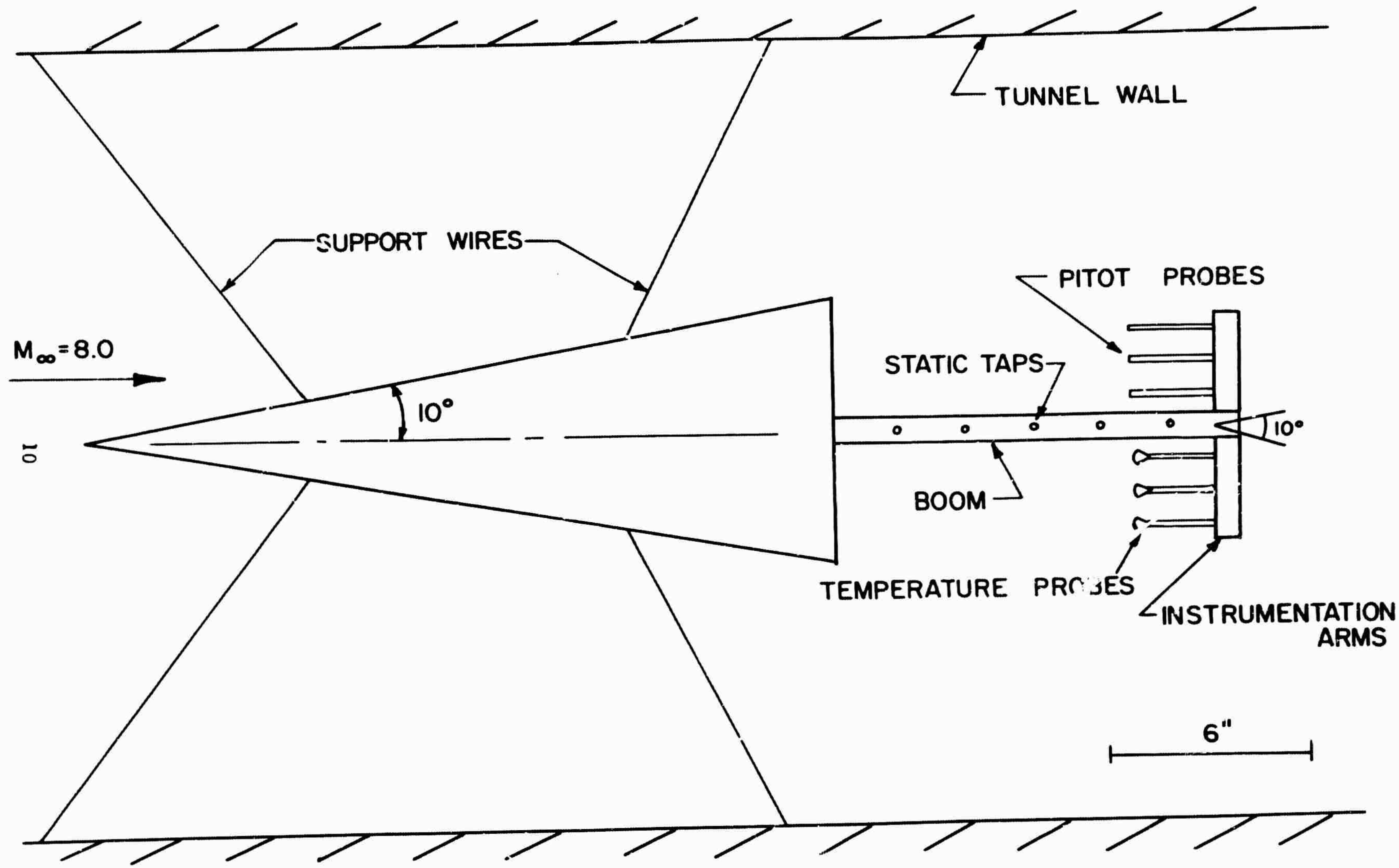

FIG. (2) TEST CONFIGURATION

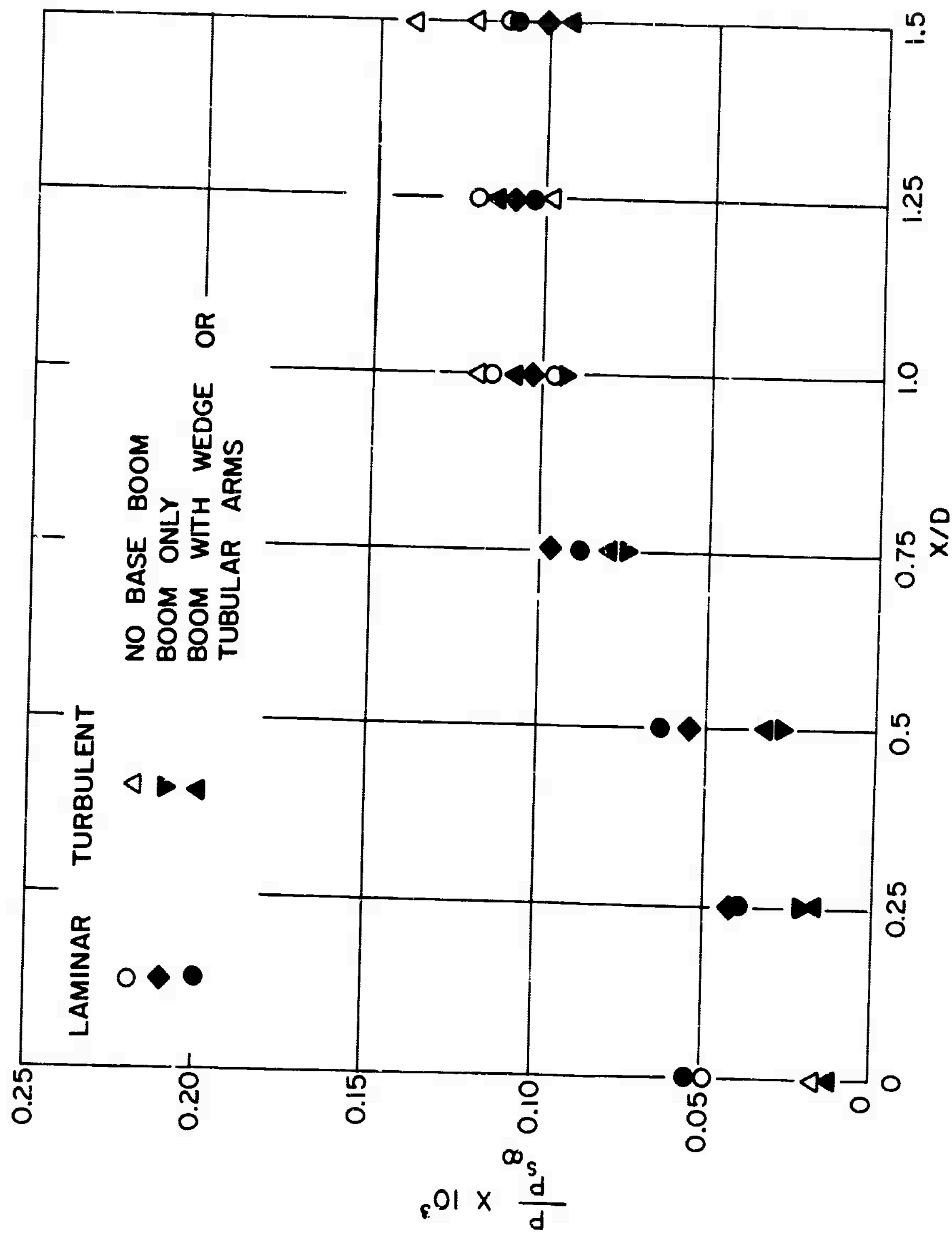

FIG. (3) STATIC PRESSURE DISTRIBUTION ON BOOM SURFACE

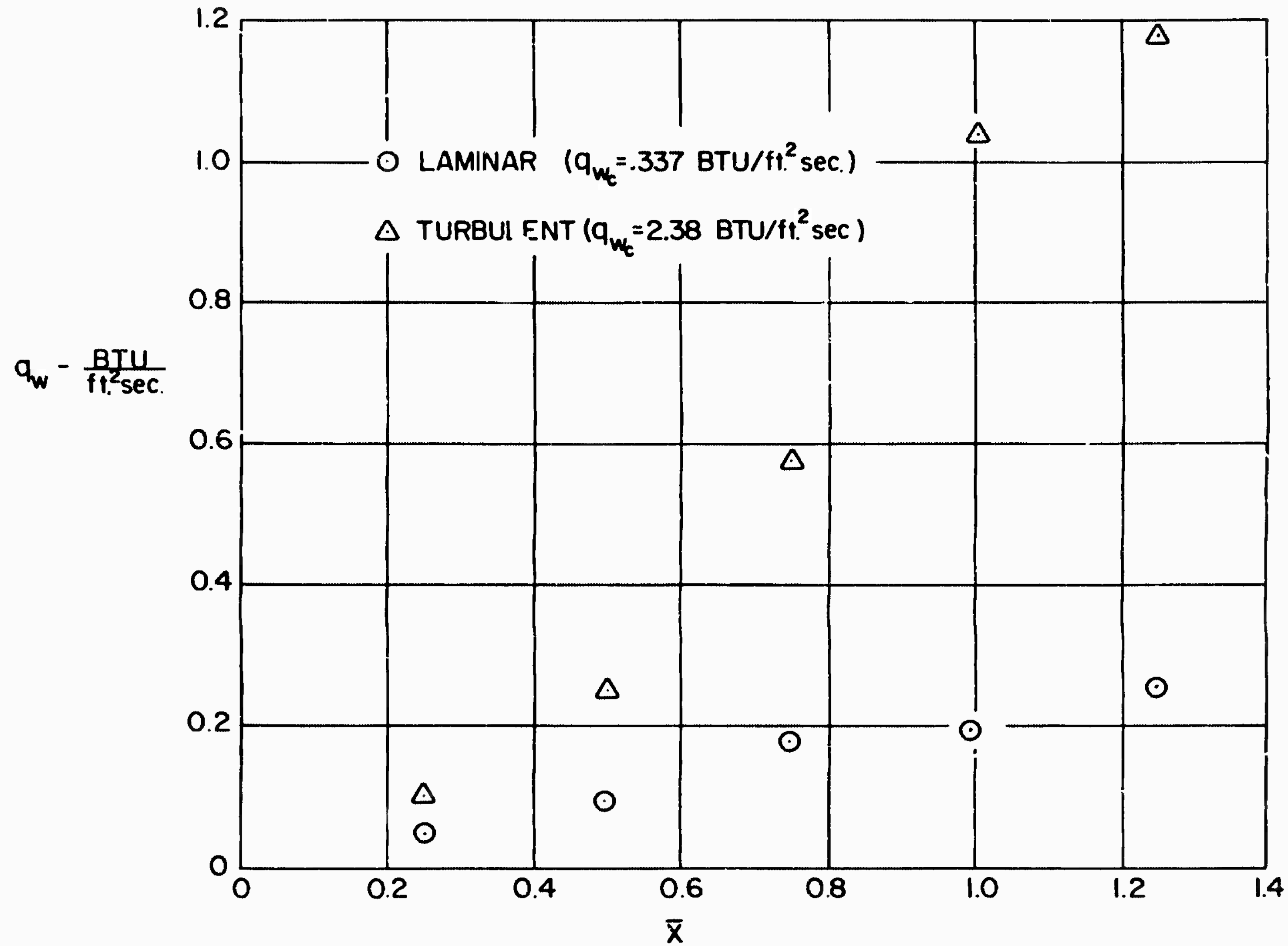

FIG. (4) HEAT TRANSFER DISTRIBUTION TO BOOM SURFACE

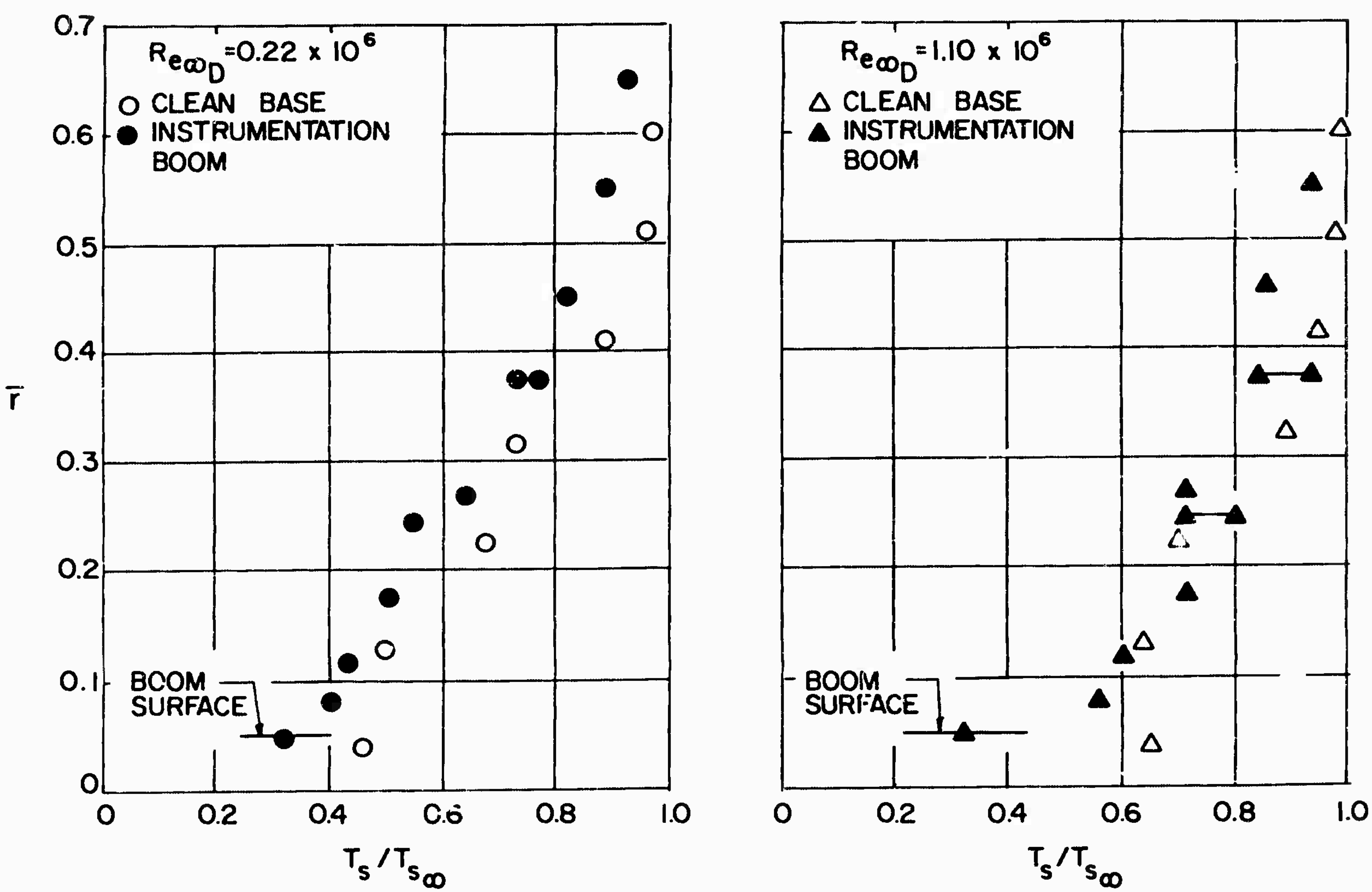

FIG. (5) STAGNATION TEMPERATURE PROFILES

(a) $\bar{X}$ = 1.0

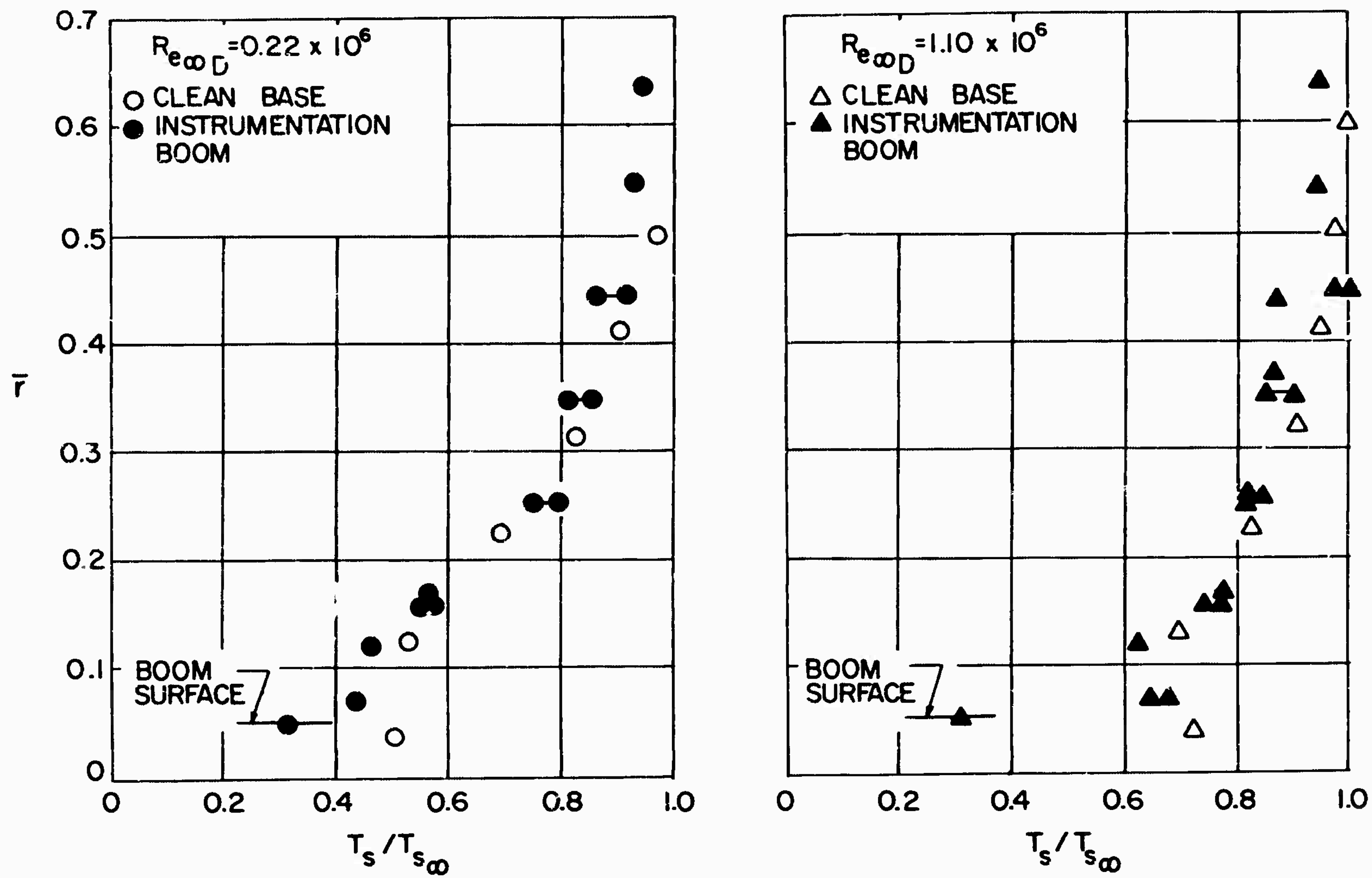

FIG. (5) STAGNATION TEMPERATURE PROFILES
(b) $\bar{X} = 1.25$

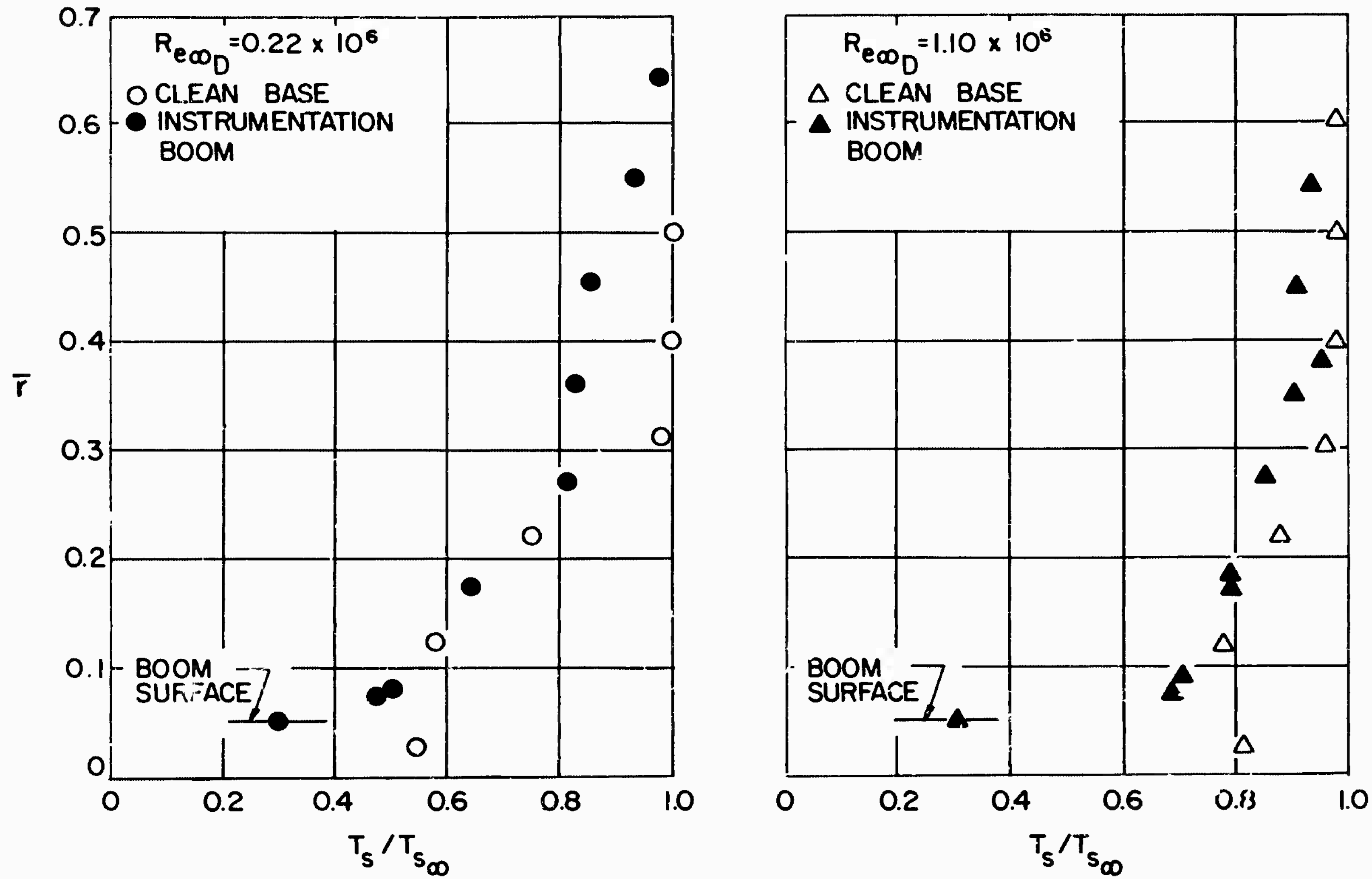

FIG. (5) STAGNATION TEMPERATURE PROFILES
(c) $\bar{X}$ = 1.5

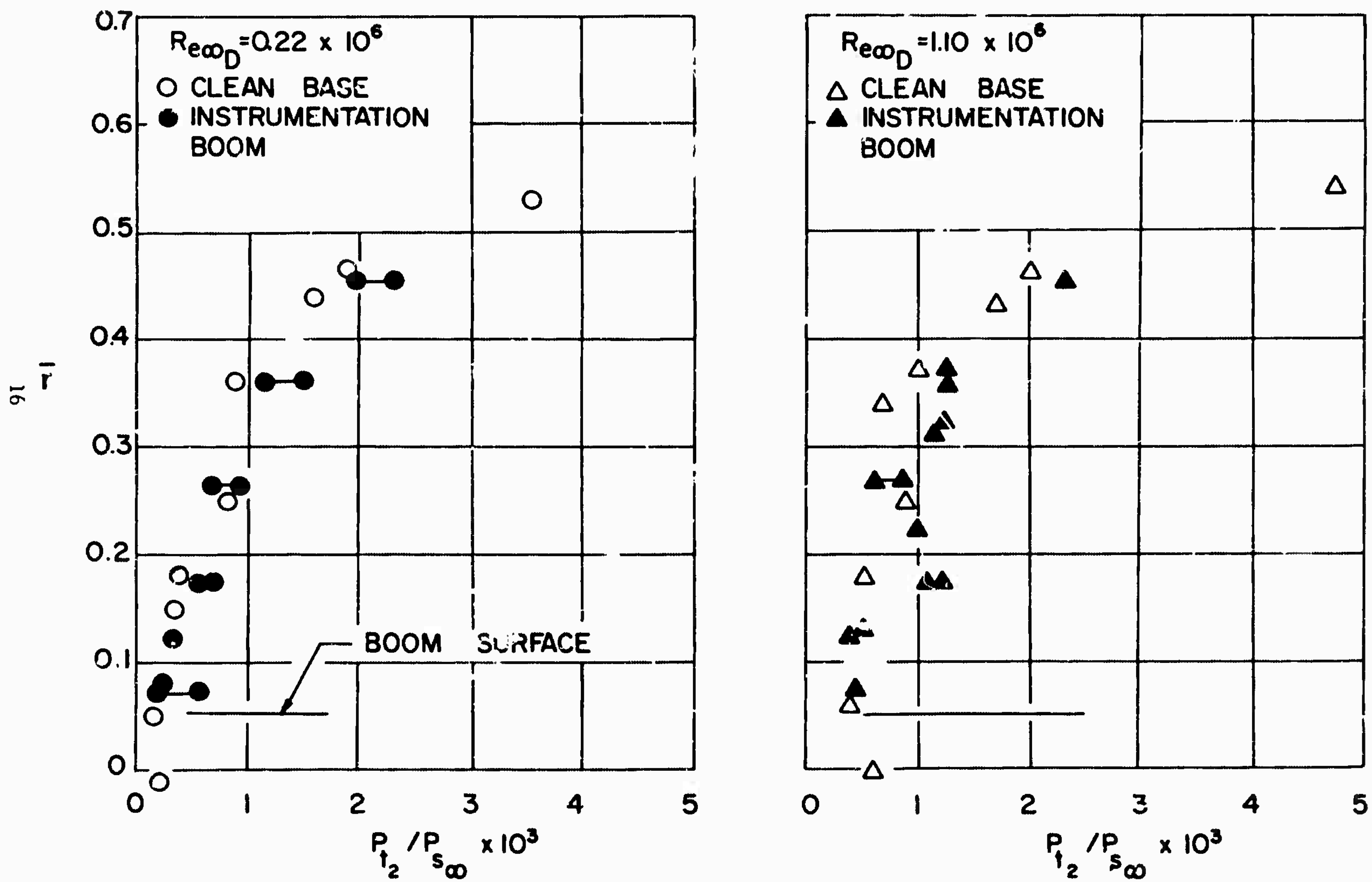

FIG. (6) PITOT PRESSURE PROFILES
(a) $\bar{X} = 1.00$

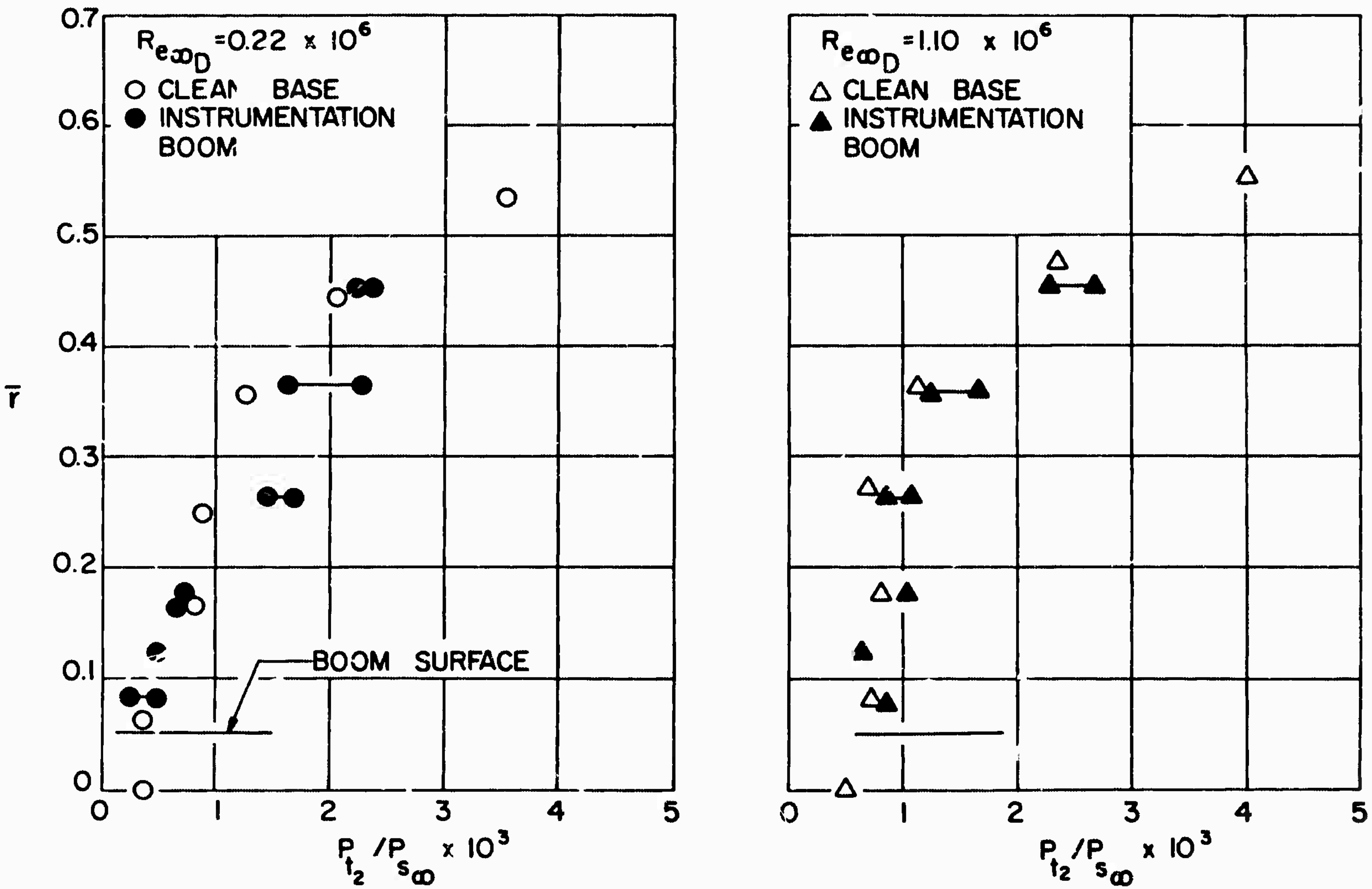

FIG. (6) PITOT PRESSURE PROFILES
(b) $\bar{X} = 1.25$

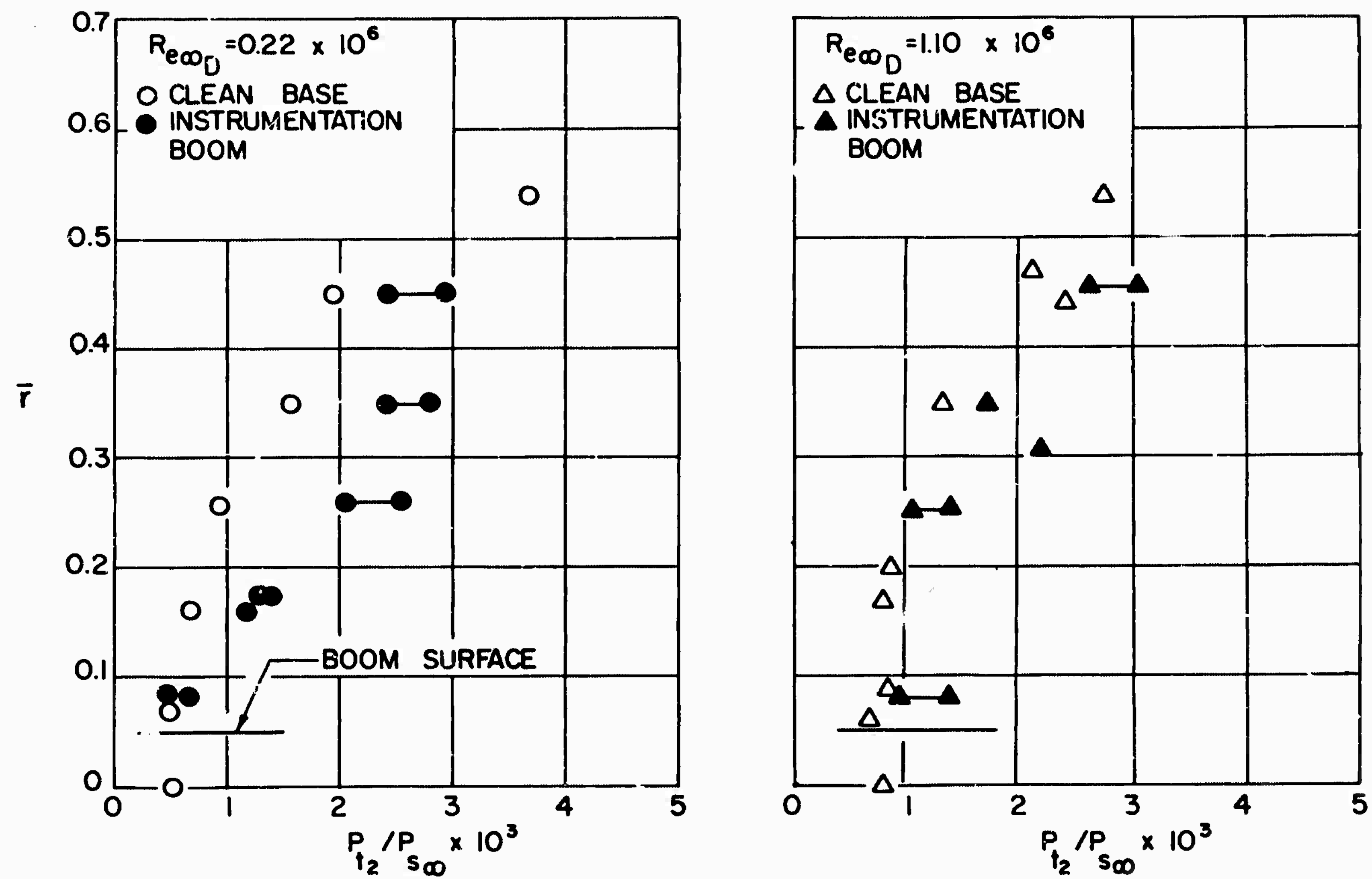

FIG (6) PITOT PRESSURE PROFILES
(c) $\overline{X} = 1.50$

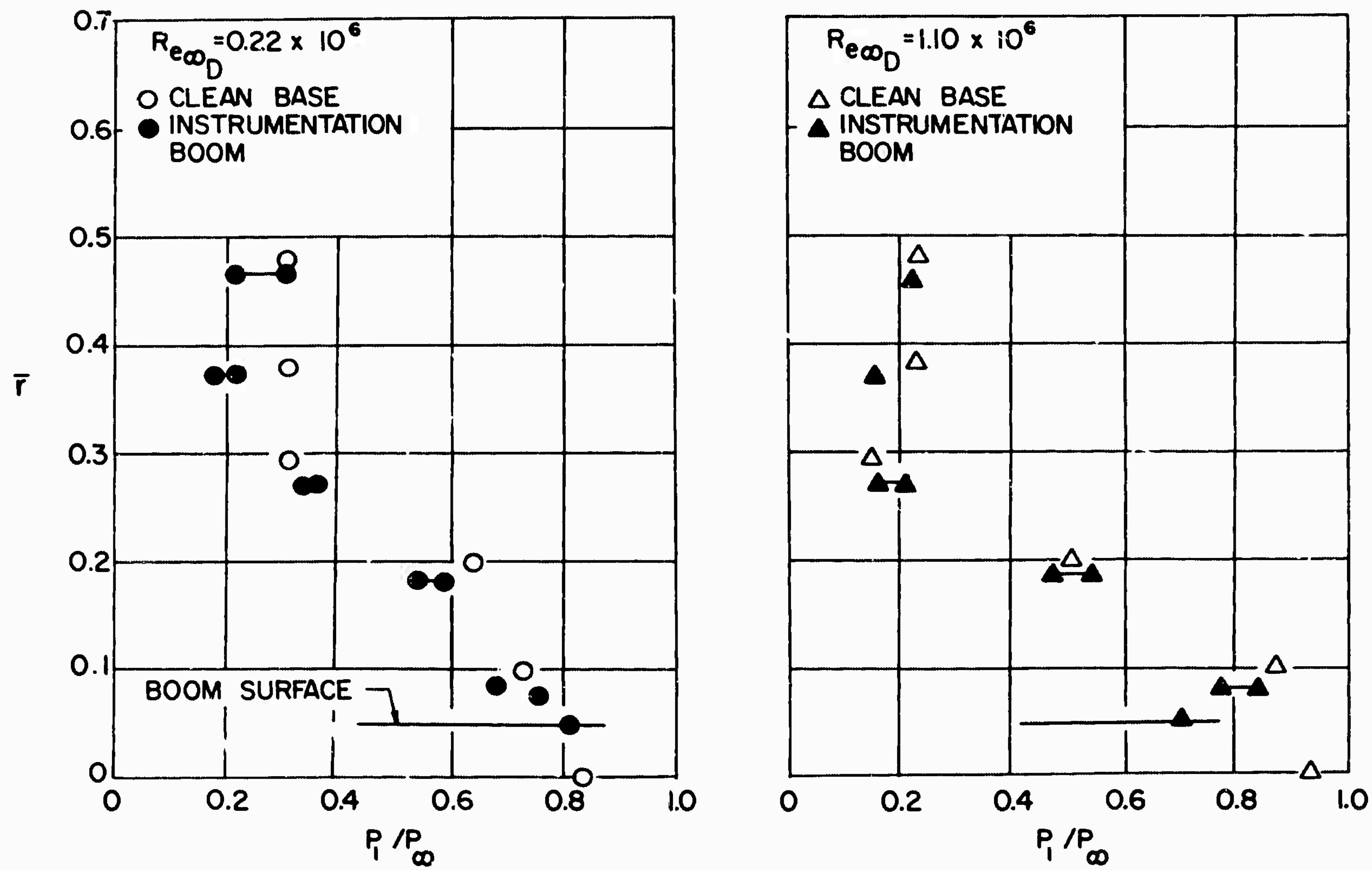

FIG. (7) STATIC PRESSURE PROFILES
(a) $\bar{X}$ = 1.00

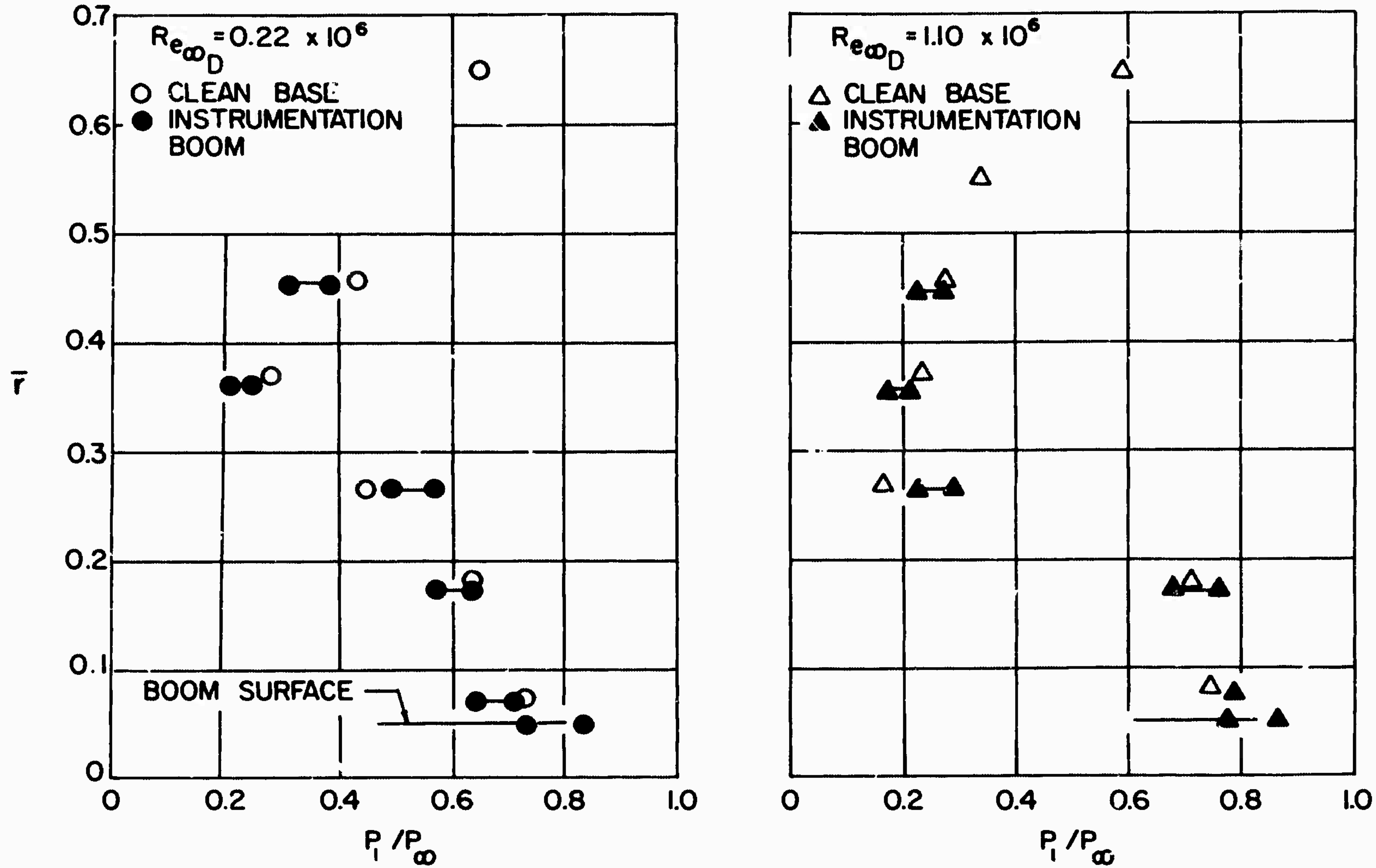

FIG. (7) STATIC PRESSURE PROFILES
(b) $\bar{X} = 1.25$

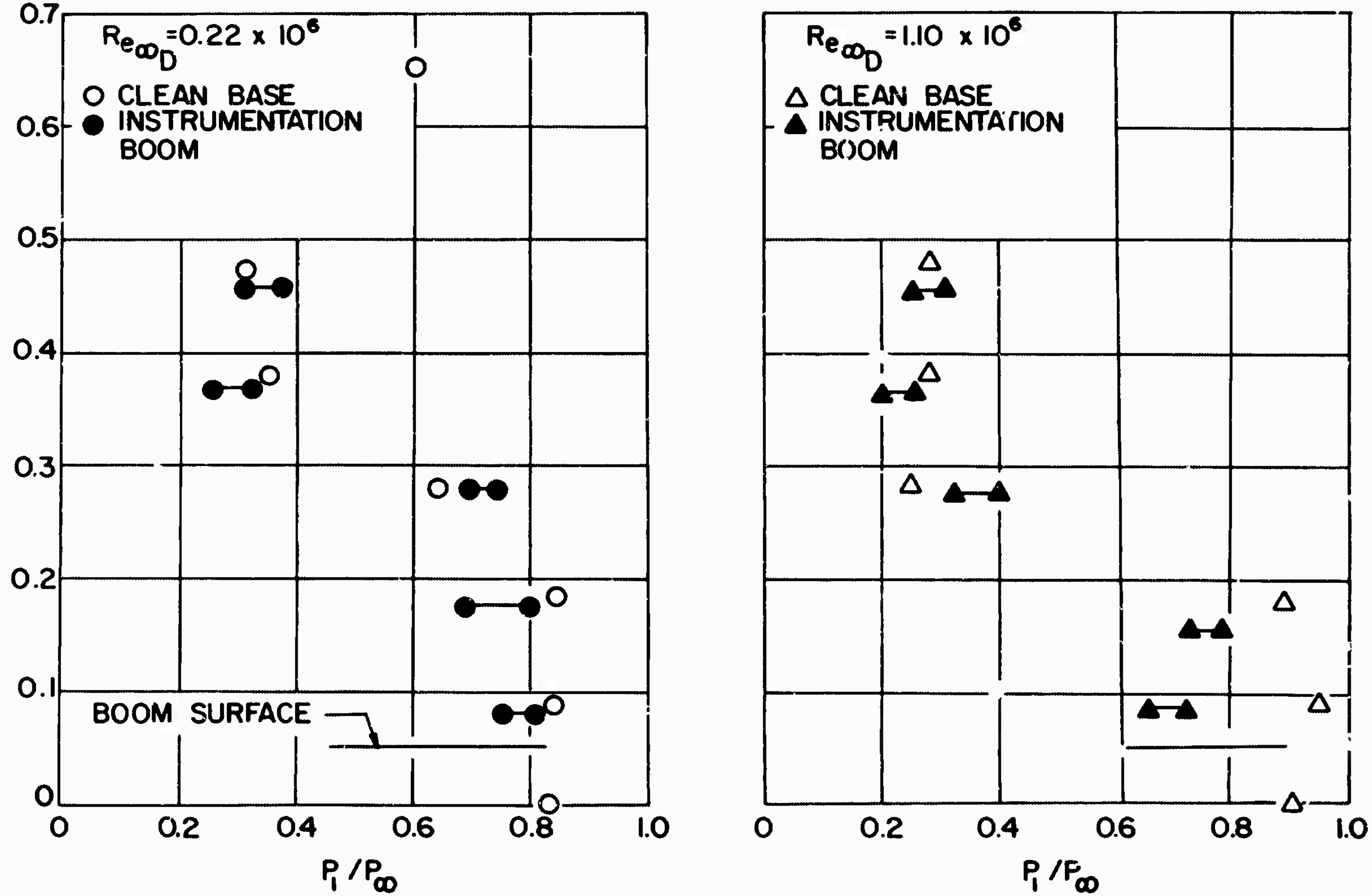

FIG (7) STATIC PRESSURE PROFILES
(c) $\bar{X} = 1.50$

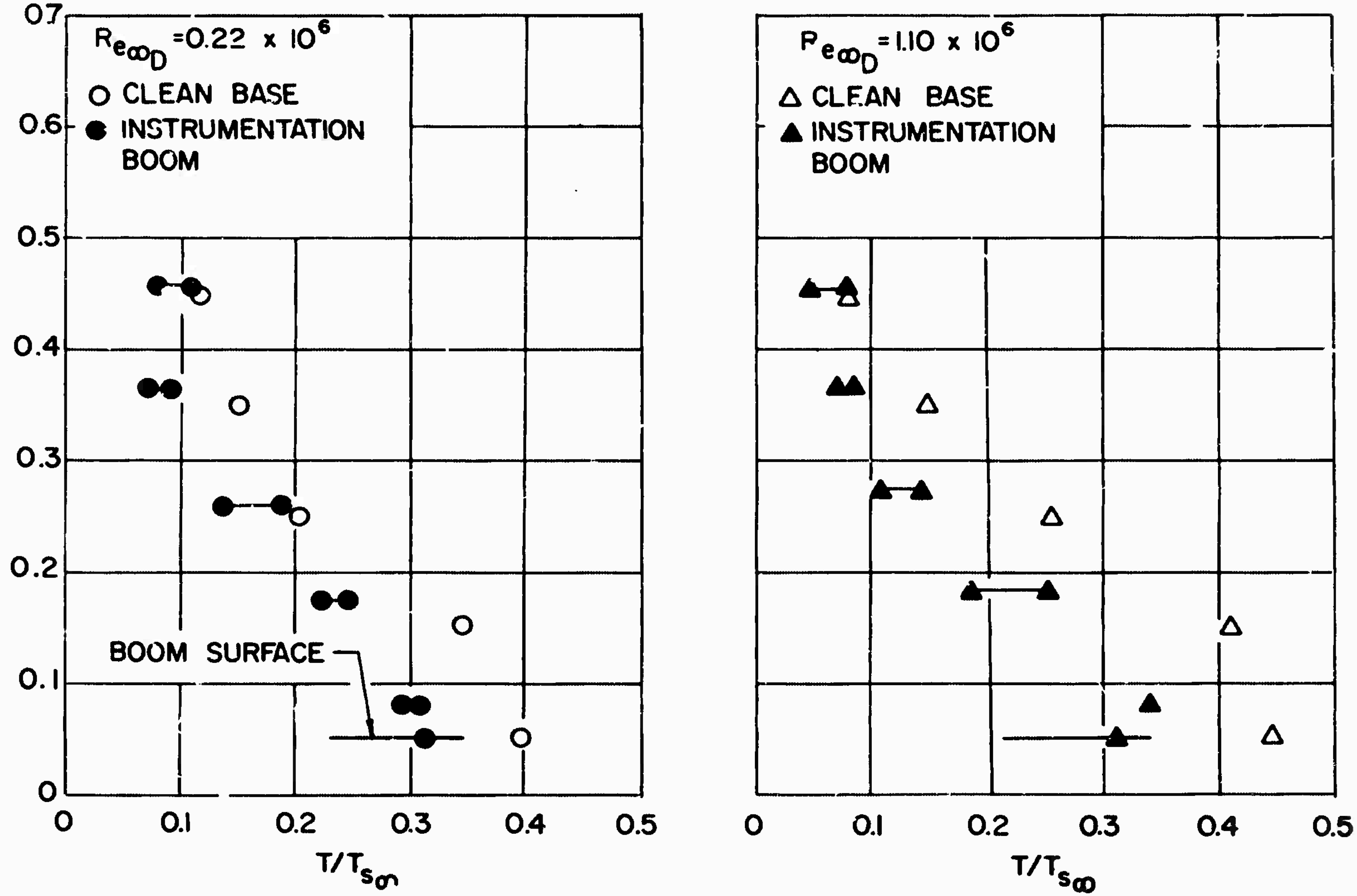

FIG. (8) STATIC TEMPERATURE PROFILES

(a) $\bar{X} = 1.00$

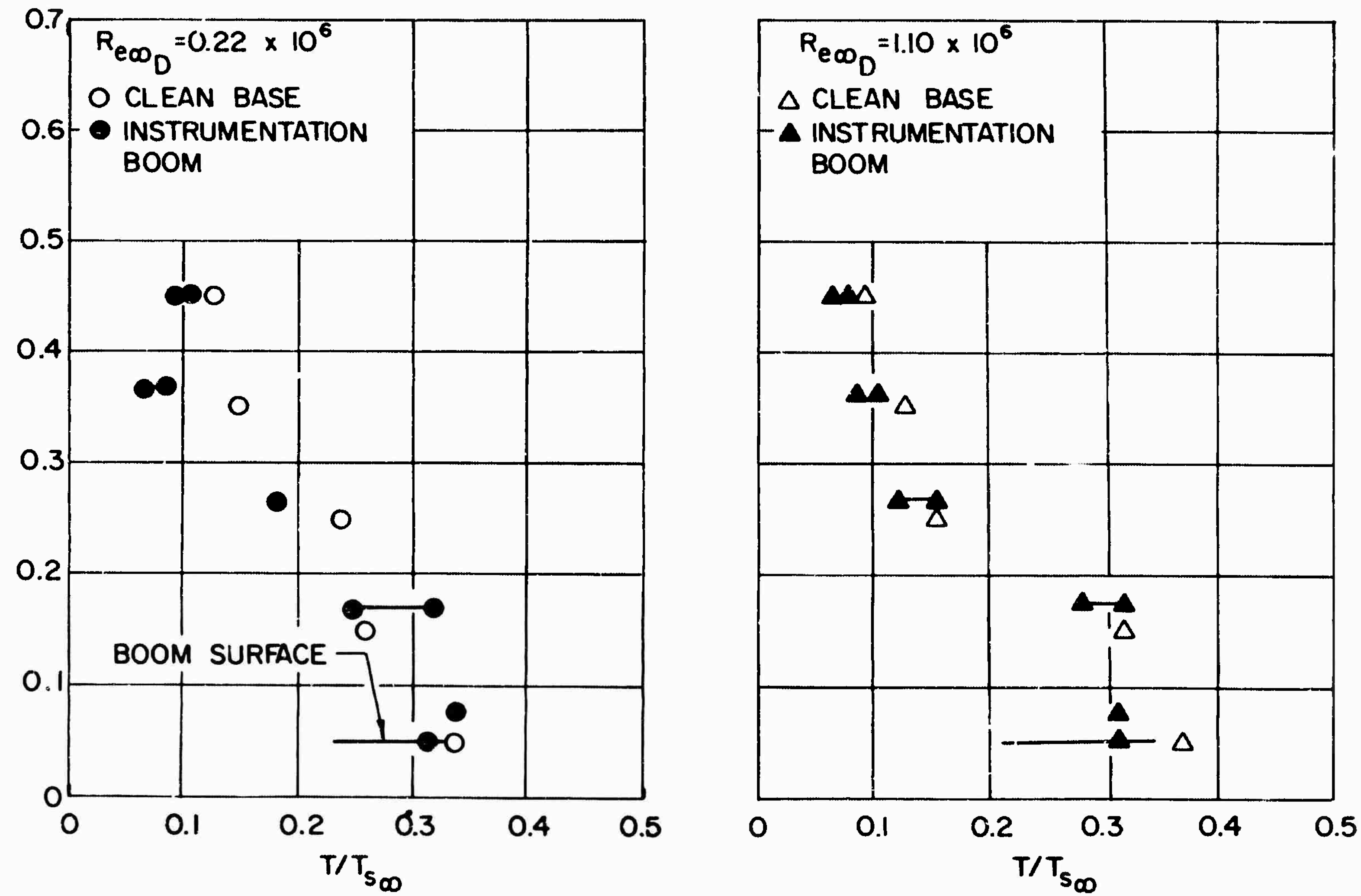

FIG. (8) STATIC TEMPERATURE PROFILES
(b) $\bar{X} = 1.25$

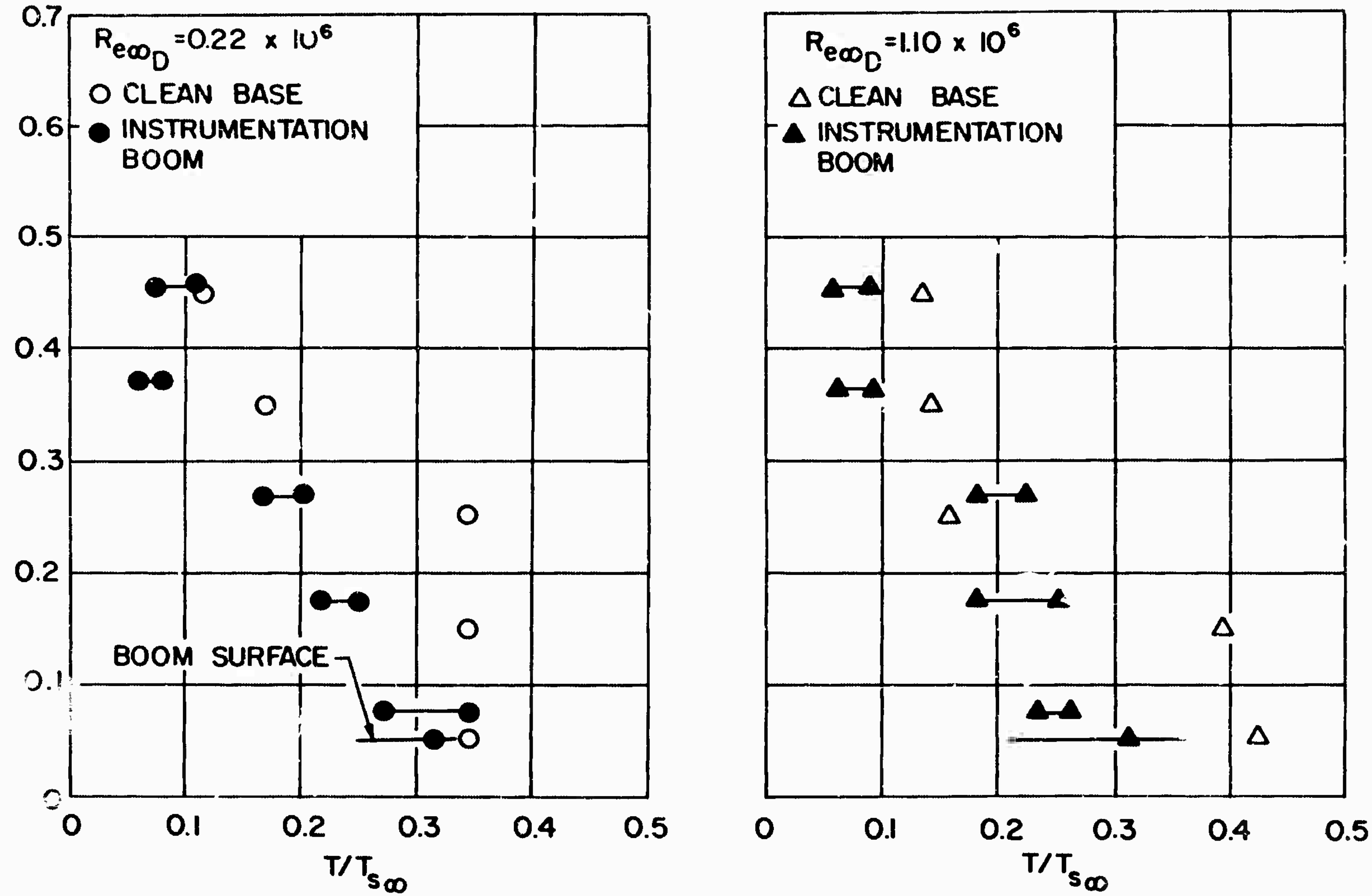

FIG. (8) STATIC TEMPERATURE PROFILES
(c) $\bar{X}$ = 1.50

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13. ABSTRACT

A series of experimental tests were run to determine the effect on the near wake flow field of inserting an instrumentation boom in the base region of a sharp cone. Test data were obtained for a free stream Mach number of 7.7, Reynolds numbers corresponding to either completely laminar or fully turbulent flow on the cone surface, and for a 10° half angle cone with a boom length of one and a half base diameters.

The data was compared to the clean base configuration and it was found that the adjacent flow field was disturbed considerably by the presence of the boom.

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Hypersonic Flow						
Separated Flow						